DESIGNING OF A MICROCONTROLLER BASED MULTI-SENSOR SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electronics & Instrumentation

by

GAURAV PRATAP SINGH

Roll No: 212EC3162

Department of Electronics & Communication Engineering

National Institute of Technology

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Under the guidance of

Prof. Santos Kumar Das

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CERTIFICATE

This is to certify that the thesis entitled, "**DESIGNING OF A MICROCONTROLLER BASED MULTI-SENSOR SYSTEM**"submitted by GAURAV PRATAP SINGH in partial fulfilment of the requirements for the award of Master of Technology degree in **Electronics and Communication Engineering** with specialization in "**Electronics & Instrumentation**" during session 2012-2014 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Date:

Prof. Santos Kumar Das
Dept. of ECE
National Institute of Technology
Rourkela-769008
Email: dassk@nitrkl.ac.in

Acknowledgment

I would like to express my gratitude to my thesis supervisor Prof. Santos Kumar Das for his guidance, advice and constant support throughout my thesis work. I would like to thank him for being my advisor here at National Institute of Technology, Rourkela.

Next, I want to give regards to Prof T. K. Dan, Prof. U. C. Pati, Prof. S.K. Patra, Prof. S. Meher, Prof. K. K. Mahapatra, Prof. S. K. Behera, Prof. Poonam Singh, Prof. Samit Ari, Prof A. K. Sahoo and Prof D. P. Acharya for teaching me and also helping me to learn. They always have been a great sources of information and inspiration to me and I am sincerely grateful to them for they have shown generous help in many ways to complete this thesis.

I would like to express gratitude to all my classmates and mostly to Deependra Bapna and Varun Shrivastava for all the helpful and mind innovative deliberation that we had, which encouraged us to imagine way beyond the obvious. I've relished their "esprit de corps" so much in my precious time at NIT, Rourkela.

I am especially obligated to my parents for their compassion, expense, and support. They have taught me from the time I set foot in this world and have set great examples for me about how to live, study, and work.

GAURAV PRATAP SINGH

Roll No: 212EC3162

Dept. of ECE

NIT, Rourkela

ABSTRACT

A wireless network containing small interdependent sensor nodes is called WSN (wireless sensor network). Environmental quantities like Light, Temperature, Pressure, Motion, Humidity, Sound etc. are to be measured and monitored with the help of this system. The data that is measured by these sensor nodes is sent to a base station using RF (radio frequency) communication. The communication between the nodes and the base station can be a single hop communication or it can be a multi hop communication depending on the remoteness of the sensor node. The base station also controls the whole network.

On each sensor node there are various hardware components. Some of those are Microcontroller, Sensor or Transducer, Radio Frequency Transceiver, Battery or some other power source. Several other components are used for signal processing purpose to bring the sensor output signal in proper form and for proper power supply required for main components. The components required for this purpose are voltage regulators, Amplifiers, resistors, capacitors and crystal oscillator of different frequencies.

The main aim of this thesis is to achieve the communication between different sensor nodes and a single receiver simultaneously. The receiver that is base station should be able to display the information received from the sensor nodes.

Three similar nRF24L01 nodes were designed and tested to check their functionality. An Attiny85 microcontroller was used to design the sensor nodes and at the base station ATmega328 microcontroller was used. These microcontrollers are programmed in C with Arduino 1.0.5-r2. The signal received from the sensors is converted from analog to digital by the Attiny85 microcontroller and delivered it to nRF24L01+ where it is sent by the radio. The communication between base station and PC is established by a USB connection.

Keyword: WSN, nRF24L01+, AT mega, Attiny85, Arduino.

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Chapter 1

Introduction

1. Introduction

This project focuses on the designing and construction of a wireless sensor node. It also covers the programming and testing of microcontroller mounted on the nodes. The nodes will use nRF24L01+ module to communicate with each other. The programming language is used to program the microcontroller is C and C++.

1.1.Motivation and Objectives

For low data rate applications that requires certain kind of sensing and actuation wireless sensor networks are used. These can be adequate for application that combines or has following characteristics: Difficult environment conditions like nuclear plants, mines, and industrial plants, underwater monitoring etc. large and remote areas (forests, mountains ranges, and sewer systems). A large number of nodes are required for this purpose. Nodes will have a little or no maintenance usually because of remoteness or inaccessibility of the area where these nodes are installed.

The primary function of the node will be to monitor that particular physical quantity and send it to the base station. The possible secondary functions of the nodes will be limited by the number of sensors that a node can have at the same time. This secondary function of nodes will depend on the size, power consumption, and the microcontroller used etc.

The motivation for the matter presented in this thesis is the large number of benefits that we can achieve using a multisensory system. In harsh environments, a multi sensor system is aimed to get predictability in time critical radio frequency communications. The final output of this project can be used for home security and some industrial applications. This might well be understood as a motivation for this project in a way.

The main objectives of this project are as following:

- The designing and construction of a wireless sensor node.

- Programming of microcontroller in C and C++. The microcontroller used are ATtiny85 and ATmega328 which are manufactured by Atmel Corporation.
- An nRF24L01+ module will be used for communication.
- The physical quantity will be measure by the sensor embedded in the node and data will be sent using wireless connection.
- The nRF24L01+ module and microcontroller will be communicating using SPI interface. This interface will be implemented using SPI (serial peripheral interface) pins on both ends.
- A battery and voltage regulators will be used to supply proper power for the components.
- A USB port will be used to power up the base station and this will also be used for the communication between base station and PC.
- Three different sensor nodes that are Light sensor, motion sensor, and temperature sensor will be mounted and will be tested for the right functionality.

1.2. Thesis description

This “DESIGING OF A MICROCONTROLLER BASED MULTI SENSOR SYSTEM” final thesis is an amalgamation of seven chapters that contains and elaborates precise areas such as the Introduction, Work planning, Designing of the system, Results and discussion, Conclusion and Further Development that can be applied in this project.

Chapter 2, Methodology and work planning, describes the brief the method to be adopted and the tools required to implement the system.

Chapter 3, State of Art, give the insight about the new technology that is used in implementation of this project

Chapter 4, Hardware Design, gives a brief idea about the hardware components that are used in this project.

Chapter5, Software and Hardware Implementation, describes the implementation process of software as well as hardware part of the project.

Chapter 6, Result, describes the results and comments on functionality of the system.

Chapter 7, Conclusion and Future Work, gives the conclusion about the results and functions of the system. Also gives the idea about the future developments and corrections that can be done in the system to improve functionality.

Chapter 2

Methodology and Working Plan

2. Methodology and Working Plan

The following strategy will be applied to design this project:

1. Literature Review: This will be done at the starting of the project or at the starting of each new stage to get the proper knowledge, understanding of the concepts and working of hardware components. It is also necessary to get acquainted with the tools we will be using.
2. Identification of the components and tools required and choose the best component available.
3. Testing of the sensors at bread board.
4. Connection of the sensors with microcontroller.
5. Connection of nRF24L01 with microcontroller and data transfer from microcontroller to nRF24.
6. Programming of the microcontrollers.
7. Test the whole system for simultaneous reception of data.

2.1. Available Means and Tools

The means and tools used are provided by "ECE Department, NIT Rourkela". They are as following:

- Hardware components (microcontrollers, Nrf24 modules, sensors,)
- Components required to design electronic circuits and soldering.
- Arduino Uno to program microcontrollers.
- Arduino 1.0.5-r2 compiler.

Chapter 3

State of Art Technology

3. State of Art

This part covers the discussion about wireless sensor network and nRF24L01+. This information is not usually necessary to design this project but it is useful to understand the purpose and it will help in decision making at the time of designing. Basic programming of microcontrollers and hardware design knowledge is necessary to understand well the designing and construction of the project.

3.1. Wireless Sensor Network

Some applications that involves a particular type of sensing they do not facilitate high data rates in the scope of wireless networks. The wireless networks, working in this manner and supporting the low data rates do fall in the category of wireless sensor networks (WSN).

According to Javier Garcia Castano to design a WSN some design challenges are faced:

- Low power consumption: batteries should be having a longer life.
- Range: range of the communication is specification that is to be accomplished.
- Frequency band availability worldwide
- Topology of the network: network topology depends on the application- mesh, ring, star, and tree. Each topology will need a specific protocol to operate.
- Security: network should be authentic and its integrity is an important feature.
- Data rates: In WSN high data rates are not required but data rates should be at a minimum level.
- Size: size of the nodes should be as minimum as possible.
- Message latency: although it is not very limiting specification still there should be a maximum limit on message signal latency.
- Rigidity: sensor nodes should be rigid enough to bear harsh environment conditions.
- Reliability: communication between base station and sensor nodes should be reliable.

Some of the applications and areas where WSN can be very useful are as follows:

- Process control and monitoring: In industries it is required to control and monitor different processes and machines. The chemical product concentration, temperature, speed of motors, humidity, and gas compositions can be monitored using wireless sensor networks.

- Environmental monitoring: a WSN can be employed in any desired area to get the information about any changing environmental quantity like temperature, sun light, flow of a river, seismic or volcanic activities (figure 3.1), humidity of air, air pollution, water level etc.
- Agriculture: WSN can gather information about soil moisture, sun light, rain water lever and soil composition.
- Patient monitoring system: WSN can be used to monitor a patient condition in a hospital room. WSN can be used to monitor blood rate, glucose level, and body temperature. It is also useful to store and process the gathered data from long time observation of the patients and their test results.
- Home security and automation: in smart home scheme WSN is used for ensure the security of a house. Also it can be used to automate the home electrical appliances. Motion sensors and door lock system are used for the purpose of home security. WSN are also used in remote controlling of different home appliances as television and wireless mouse and keyboards.

The applications stated above are just a glimpse of what WSN can be capable of if used at appropriate places. It can also be useful in many other areas like Context-aware computing, Battlefield awareness (e.g. multi target tracking), Infrastructure protection (e.g. power grid, water distribution), and biometric attendance system in offices.

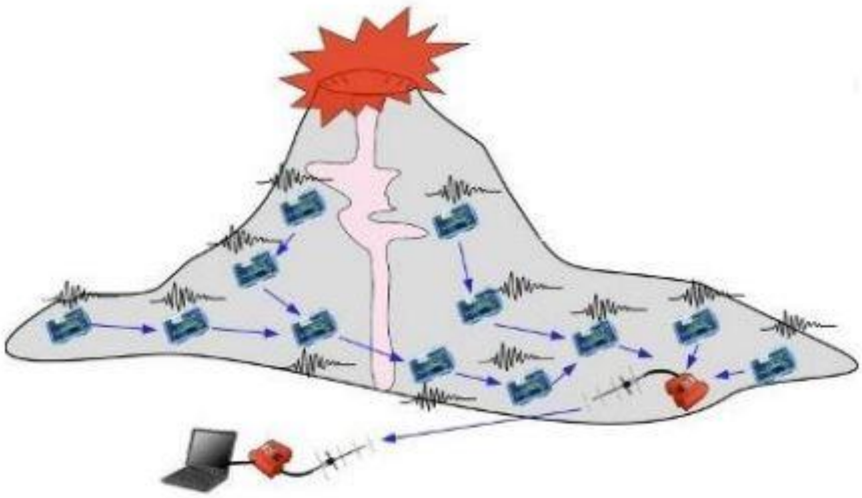


Figure 1: WSN monitoring an active volcano

3.2.Gaussian Phase Shift Keying Modulation (GFSK)

GFSK modulation is used by Nrf24L01 to send the data using wireless link. This part of the thesis covers the background and basics of GFSK modulation.

3.2.1. Principle

This modulation scheme is used by many standards which uses digital communication such as Bluetooth, wavenis and DECT. In digital communication the transmitting device translate the discreet alphabet into a digital signal and sends it to the transmitting medium and receiving device then recovers the original symbol from the digital signal.

In digital communication there are only two discreet symbols 0s and 1s. These symbols are named as bits as they are only two symbols to represent an alphabet. This modulation scheme is derived from the frequency modulation. In FSK modulation whenever the bit is 0 the carrier frequency decrease for that amount of time and carrier frequency increases for the time duration of bit 1. If the square wave that will be used to vary the frequency of the carrier signal is filtered with Gaussian filter, the modulation scheme will be called Gaussian FSK.

In real-world systems a high frequency carrier is used to propagate the signals between transmitter and receiver antennas. This high frequency is called radio frequency (RF). At the transmitting end some analog devices are used for up conversion of RF and at receiver end for down conversion of intermediate frequency. Analog to digital convertor is used to get back the digital signal from analog signal at receiver side.

3.2.2. Transmitter

The signal which is transmitted by antenna can be written as follows. It is having a time dependent phase.

$$s(t) = V\cos(\omega t + \varphi(t))$$

In this equation V is the signal's amplitude. It is a constant as amplitude will not be affected by modulation.

From the transmitted bits we can derive the phase which is:

$$\emptyset(t) = \mu\pi \int_{-\infty}^{t} \sum_i a\gamma(\tau - iT)dT$$

Where modulation index is given by μ: if modulation index is having a larger value the bandwidth of the modulated signal will be high with the same extent. If modulation index has zero value than it is representing an unmodulated carrier.

Sequence number is denoted by "a": it is having a value +1 if bit is 1 and a value -1 if bit is 0.

Frequency pulse is denoted by $\gamma(t)$. A rectangular pulse of $1/_{Ts}$ would be representing the frequency pulse in the interval [0, Ts]. It will be zero outside this interval and Ts is the time duration of each symbol. So if we ignore the polarity of "a" then $\mu\pi$ will be the phase contribution of each symbol. Phase shift of $\frac{\mu\pi}{Ts}$ will take place if we transmit a continuous series of 1s for the time period of 1 sec. This phase shift which takes place in 1 sec is called as angular frequency shift. Hence $\frac{\mu\pi}{Ts}$ will be the actual frequency shift. It shows that FSK signal is having either instantaneous frequency $f - \frac{\mu}{2Ts}$ or $f + \frac{\mu}{2Ts}$,if we ignore the effect of switching that takes place between these frequencies. The shape of frequency pulse will be smoothened by Gaussian filter and it will increase its width so that its period will be more than
Each symbol period though inter symbol interference will take place due to this. The avoidance of high frequencies which occurs due to switching is the main goal. When a sequence having multiple equal bits is transmitted the extremes of instantaneous are reached. Otherwise else this swing around instantaneous frequency will be small.

The equation for Gaussian filter is given by:

$$g(t) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{t}{\sigma}\right)^2}$$

Where σ is in relation with 3-dB bandwidth B of the filter.

$$\sigma = \frac{\sqrt{\ln 2}}{2\pi B}$$

It is to be noted that impulse response of Gaussian filter expands from $-\infty$ to $+\infty$. For practical purpose this span should be limited.

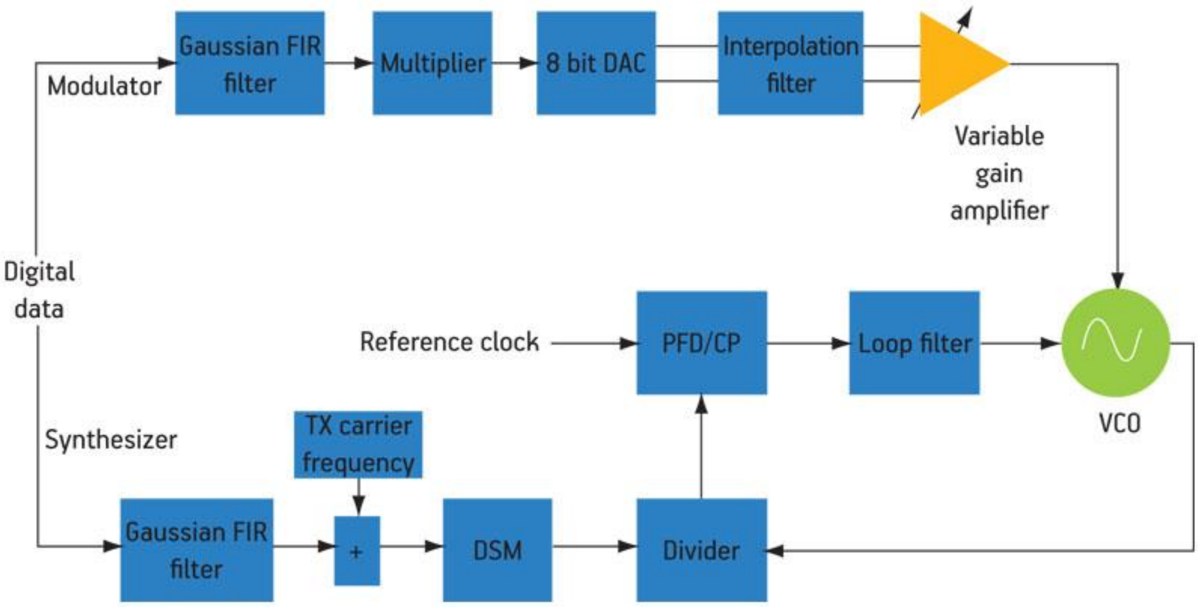


Figure 2: GFSK generator

3.2.3. Receiver

A mundane method to recover the transmitted bits from the received modulated signal is the shifting of the signal to baseband signal. In this method the carrier frequency is reduced to zero. The signal is then filtered and a delay/advance multiply transformation is applied. The steps for this process are shown below:

Equation for transmitted signal is modified to:

$$s(t) = A\cos((\omega_{\mathrm{IF}} + \omega_d)t)$$

Here ωd is derivative of phase $\omega d = \frac{d}{dt}\emptyset(t)$ and also called instantaneous frequency offset which is caused due to modulation. So if we are able to get the value of ωd for a particular symbol time period we will get the bit value from the polarity of ωd. If $\omega d > 0$ then the bit received was 1 and if $\omega d < 0$ then a 0 bit was received.

In order to avoid the instantaneous frequency we will multiply transmitted signal with unmodulated sin and cosine.

$$i_m(t) = s(t) \cdot \cos(\omega_{\mathrm{IF}} t)$$
$$q_m(t) = s(t) \cdot -\sin(\omega_{\mathrm{IF}} t)$$

This process is known as mixing. The two signal in above equations are called inphase and quadrature phase parts of the newly generated signal.

With the help of trigonometric product rule we will get:

$$i_m(t) = \frac{A}{2}\left(\cos((2\omega_{\mathrm{IF}} + \omega_d)t) + \cos(\omega_d t)\right)$$
$$q_m(t) = \frac{A}{2}\left(-\sin((2\omega_{\mathrm{IF}} + \omega_d)t) + \sin(\omega_d t)\right)$$

Both in phase and quadrature phase components will now have the pristine signal twice: one is having center frequency zero and other is having center frequency $2\omega_{\mathrm{IF}}$. The signal component centered at $2\omega_{\mathrm{IF}}$ is to be abstracted by low pass filter.to get:

$$i_l(t) = \frac{A}{2}\cos(\omega_d t)$$
$$q_l(t) = \frac{A}{2}\sin(\omega_d t)$$

Parameter	Value
symbol rate	500 kHz
modulation index h	0.5
input sample frequency (ADC output)	8 MHz
hardware clock frequency	8 MHz
ω_{IF}	1 MHz
bandwidth low-pass filter	1 MHz

Table 1: Problem specification for GFSK

The delay and multiply operation is common scheme for FM demodulation.

$$d(t) = q_l(t) \cdot i_l(t - \Delta T) - i_l(t) \cdot q_l(t - \Delta T)$$

Once again when we apply the product rule for trigonometric functions:

$$d(t) = \frac{A^2}{4}\sin(\omega_d \Delta T)$$

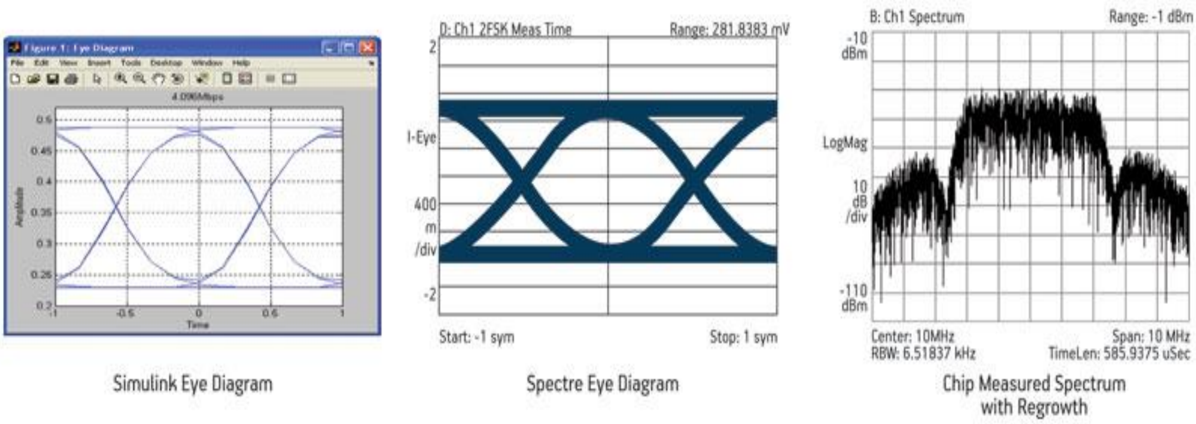


Figure 3: GFSK spectrums

Chapter 4

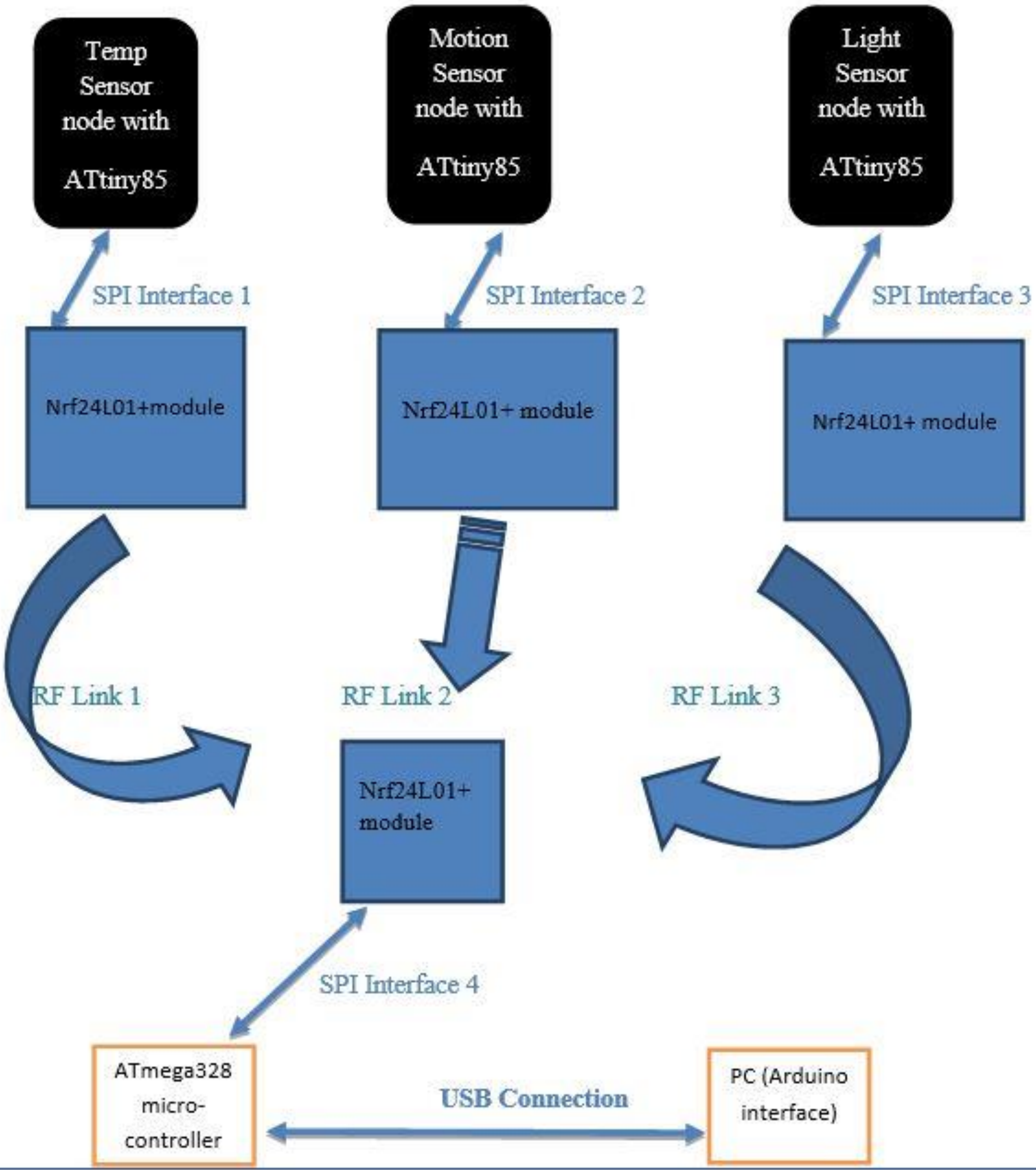
Hardware Design

4. Hardware Design

This part covers the summary of hardware design at first. Then the components that are used to construct the hardware are described in detail and their functions are also explained. The connections that are to be made in between those components are also depicted in this section with schematic diagrams.

4.1.Hardware Design Overview

Figure 4: Basic Block Diagram of Project



4.1.1. The Sensor Nodes

The sensor nodes contains a sensor and microcontroller (in this case ATtiny85). Sensors acquire the data and send it to microcontroller. All these sensor (temperature, motion, and light) send the analog data to microcontroller. To make the data understandable to microcontroller it needs to be converted into digital form. It is done with the help of an ADC convertor which is integrated in the microcontroller.

Some sensors already have an ADC integrated to it. Hence their data need not to be digitized.

4.1.2. Nrf24L01+ Module

These Nrf24 modules performing at 2.4GHz frequency are radio frequency transceivers. This module is designed by Nordic Semiconductor. This module is very much applicable for applications that needs ultra-low power for wireless data communication. Its interface to the microcontroller is done via SPI interface.

These modules sends the data to the microcontroller after receiving. Also microcontroller sends those commands as well as data which is processed and ready to be transmitted. Microcontroller is responsible to put these modules in different modes of operation. NRF24s use GFSK modulation scheme to modulate the baseband data. They are operated with the power supply of 1.9 - 3.3 volts. Very less power is consumed in standby mode.

4.1.3. SPI Interface

The serial peripheral interface (SPI) is a synchronous data link. It is invented by Motorola. Its operation is in fully duplex mode. Single master and short distance communication link uses this interface. In this link the device communicates in master- slave configuration. The master always initialize the data frame [1].

Although multiple slaves can be there and only single master device but in this project/system we are implementing only single mater and single slave configuration. SPI is often called as a 4 wire serial bus. Serial peripheral interface (SPI) is also called as Synchronous Serial Interface.

4.1.4. Arduino Uno Board and USB Link

At receiver (base station) side an Arduino Uno board is being taken into use. This will also work as the programmer device for ATtiny85 microcontrollers. ISP connectors and SPI interface will help in the programing of microcontrollers.

This board also has universal serial bus (USB) connectivity with PC. For display purpose the information transferred from nrf24 can be sent to PC with the help of USB interface. User can give commands or data to microcontroller from PC. The USB connection ensures user to perform following tasks [2]:

- A user can send command word from PC to microcontroller. That sent command word can be addressed to microcontroller or to nrf24 module. If command is meant for microcontroller then it will be processed there otherwise it will be sent to nrf24 and will be processed there.
- Digital Data received from sensors can be transferred to PC and this data will be displayed and will be used for controlling purposes.

4.2. Components

This part of the thesis describes the basics about each component. These components are used to implement the sensor nodes and receiver node (base station) as well. It also covers the selection criteria if it was a possibility of selecting between different devices of different capabilities. For each component a circuit diagram is also sketched.

4.2.1. Microcontroller

Microcontrollers used for this project are Attiny85 and Atmega328. Both the microcontrollers are of same family. Both microcontroller transfer 8-bit data but have different number of pins. For sensor nodes attiny85 microcontroller is used and for receiver ATmega328 microcontroller is being used.

I. ATtiny85 Microcontroller

- ➢ It consumes low power.
- ➢ In active mode it uses 300 μA when powered at 1.8 V.
- ➢ Whereas there is a power down mode it uses 0.1 μA when powered at 1.8 V

- o It has register specially to reduce power which helps in reducing power.
- o The microcontroller has three types of sleep modes which is idle mode, ADC noise reduction mode and power down mode.
- o In idle mode the microcontroller wakes up when there is external/ internal interrupts.
- o In ADC noise reduction mode the noise environment of ADC is improved which increases resolution for measurements.
- o In power down mode, the clock is stopped by the microcontroller and thus initiate asynchronous communication.

Universal serial Interface (USI) features:

- o The data can be transferred synchronously with the help of two wires.
- o The data can be transferred synchronously with the help of three wires.
- o As soon as data is received interrupt is generated in microcontroller.
- o When the microcontroller is in sleep mode and USI in two wire mode, microcontroller will wake up as soon as data is received.
- o USI can detect the start condition in the data when in two wire mode and can also detect the interrupt.

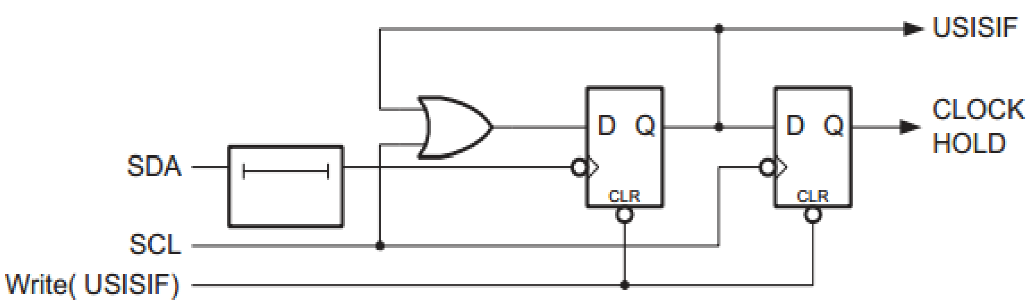


Figure 5 : Start condition detector logic diagram

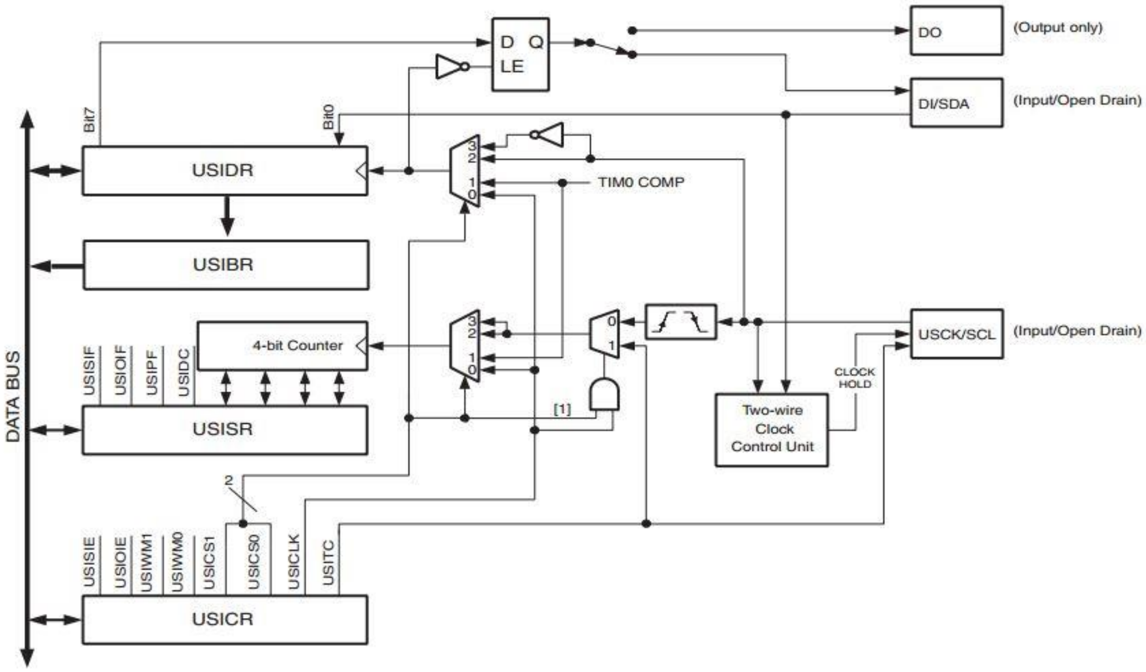


Figure 6: USI functional block diagram

- When the USI is in SPI mode 0 and 1 the USI can be said to be in three wire mode. While the CSN pin is not available functionally but it can be simulated using software implementation. The pins used by this mode are DI, DO, USCK.

Figure 6 shows master and slave USI working in three wire mode. The two USI which are shown above have such a connection between their data registers that the two registers exchange their value after every 8 clock pulses.

The generation of clock is done by master microcontroller. It toggles the pin USCK using the help from PORTB.

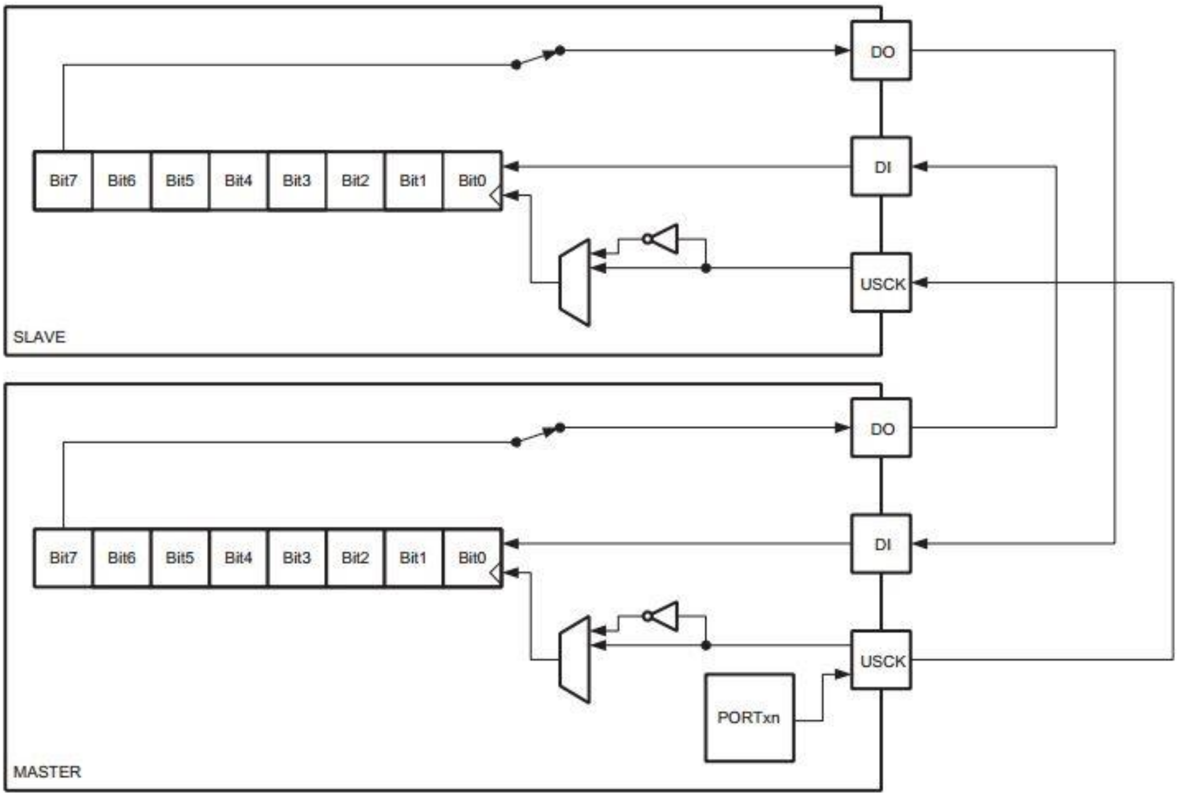


Figure 7: three wire mode operation

Peripheral Features:

- It has two PWM channels
- It has 8 bit timer/counter accompanied with prescaler
- It has double buffered compare register acting as output.
- It has glitch free PWM modulator used to correct the phase.
- Three interrupt source (TOV0, OCF0A and OCF0B) which are independent of each other
- A variable period of PWM
- Watchdog timer is programmable and has an oscillator inside.

High Performance CPU:

- A rich instruction set with advanced RISC architecture.
- There are 32 register used as general purpose register along with instruction sets
- In the execution of single instruction in single clock cycle, two independent registers can be accessed.

- It has 8kB of programmable flash present inside the system.
- 512 bytes of EEPROM and 256 bytes of SRAM.
- There are 6 I/O lines which can be used for general purpose.
- It has high density of volatile memory.
- Works when given 2.7 V-5.5 V of supply
- The oscillator is present on the chip of CPU.

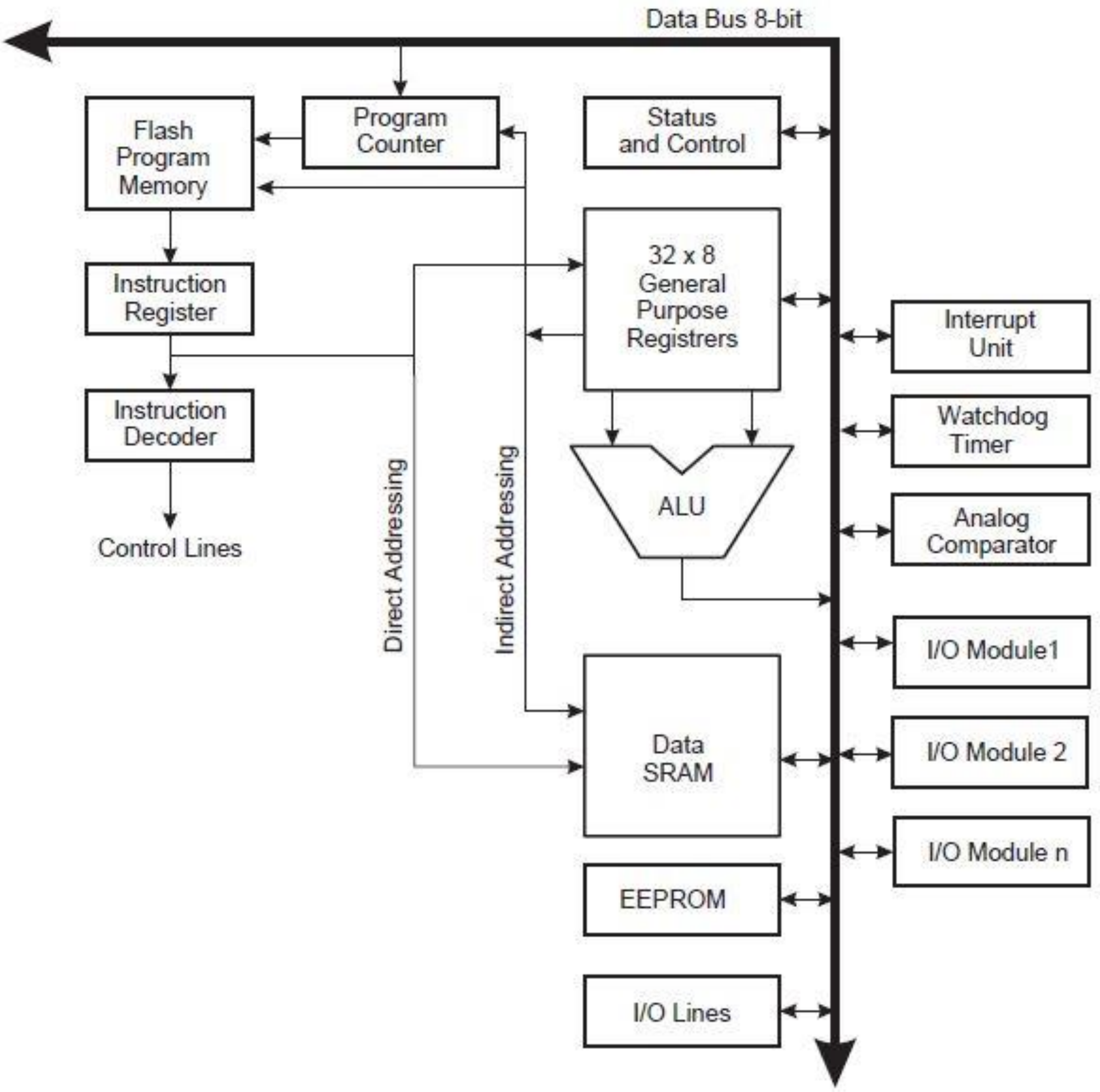


Figure 8: Block diagram of AVR architecture

Analog features:

- ADC has 10 bit of resolution and has 4 channels.

- The differential channels of ADC have programmable gain.
- The analog comparator is present on the chip itself.

Instruction Set for AVR:

Mnemonics	Operands	Description	Operation	Flags	Clock Note
ADD	Rd, Rr	Add without Carry	Rd ← Rd + Rr	Z,C,N,V,S,H	1
ADC	Rd, Rr	Add with Carry	Rd ← Rd + Rr + C	Z,C,N,V,S,H	1
ADIW	Rd, K	Add Immediate to Word	Rd+1:Rd ← Rd+1:Rd + K	Z,C,N,V,S	2 (1)
SUB	Rd, Rr	Subtract without Carry	Rd ← Rd - Rr	Z,C,N,V,S,H	1
SUBI	Rd, K	Subtract Immediate	Rd ← Rd - K	Z,C,N,V,S,H	1
SBC	Rd, Rr	Subtract with Carry	Rd ← Rd - Rr - C	Z,C,N,V,S,H	1
SBCI	Rd, K	Subtract Immediate with Carry	Rd ← Rd - K - C	Z,C,N,V,S,H	1
SBIW	Rd, K	Subtract Immediate from Word	Rd+1:Rd ← Rd+1:Rd - K	Z,C,N,V,S	2 (1)
AND	Rd, Rr	Logical AND	Rd ← Rd • Rr	Z,N,V,S	1
ANDI	Rd, K	Logical AND with Immediate	Rd ← Rd • K	Z,N,V,S	1
OR	Rd, Rr	Logical OR	Rd ← Rd v Rr	Z,N,V,S	1
ORI	Rd, K	Logical OR with Immediate	Rd ← Rd v K	Z,N,V,S	1
EOR	Rd, Rr	Exclusive OR	Rd ← Rd ⊕ Rr	Z,N,V,S	1
COM	Rd	One's Complement	Rd ← $FF - Rd	Z,C,N,V,S	1
NEG	Rd	Two's Complement	Rd ← $00 - Rd	Z,C,N,V,S,H	1
SBR	Rd,K	Set Bit(s) in Register	Rd ← Rd v K	Z,N,V,S	1
CBR	Rd,K	Clear Bit(s) in Register	Rd ← Rd • ($FFh - K)	Z,N,V,S	1
INC	Rd	Increment	Rd ← Rd + 1	Z,N,V,S	1
DEC	Rd	Decrement	Rd ← Rd - 1	Z,N,V,S	1
TST	Rd	Test for Zero or Minus	Rd ← Rd • Rd	Z,N,V,S	1
CLR	Rd	Clear Register	Rd ← Rd ⊕ Rd	Z,N,V,S	1
SER	Rd	Set Register	Rd ← $FF	None	1
MUL	Rd,Rr	Multiply Unsigned	R1:R0 ← Rd × Rr (UU)	Z,C	2 (1)
MULS	Rd,Rr	Multiply Signed	R1:R0 ← Rd × Rr (SS)	Z,C	2 (1)
MULSU	Rd,Rr	Multiply Signed with Unsigned	R1:R0 ← Rd × Rr (SU)	Z,C	2 (1)
FMUL	Rd,Rr	Fractional Multiply Unsigned	R1:R0 ← (Rd × Rr)<<1 (UU)	Z,C	2 (1)
FMULS	Rd,Rr	Fractional Multiply Signed	R1:R0 ← (Rd × Rr)<<1 (SS)	Z,C	2 (1)
FMULSU	Rd,Rr	Fractional Multiply Signed with Unsigned	R1:R0 ← (Rd × Rr)<<1 (SU)	Z,C	2 (1)
Branch Instructions					
RJMP	k	Relative Jump	PC ← PC + k + 1	None	2
IJMP		Indirect Jump to (Z)	PC(15:0) ← Z, PC(21:16) ← 0	None	2 (1)

Table 2: Instruction set for AVR

Connection Diagram: The datasheet of ATtiny85 recommend this connection. This connection is the connection used for programming of microcontroller using an ISP.

The rest of the connections which have the I/O pins and the peripherals can be seen on the other side of this thesis.

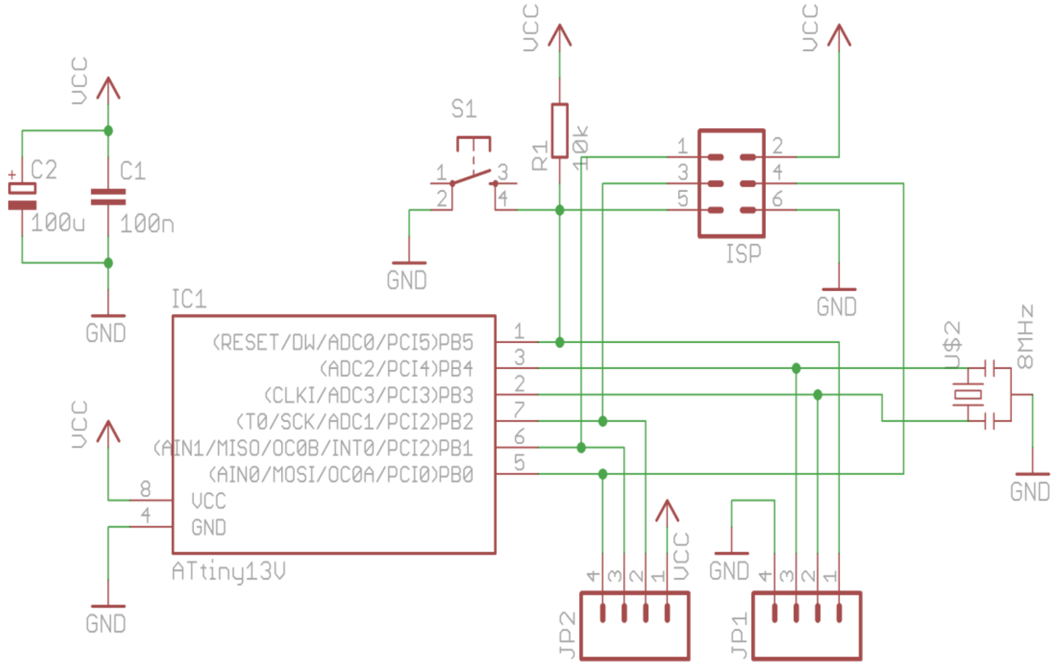


Figure 9: ATtiny85 connection diagram

II. ATmega328 Microcontroller

Arduino Uno board has ATmega328 microcontroller as its central device. It has 14 digital I/O pins. The six of the 14 I/O pins can be used as PWM channels

It has 16 MHz crystal ceramic oscillator, an in system programming (ICSP) header, a power supply jack, a USB connection, and reset button. It has each and everything which is needed to work with a microcontroller. Its feature summary is given as following [2]:

- It operates at 5 V.
- The current at each I/O pin is 40mA.
- The current for pin which uses 3.3 V is 50mA.
- ATmega328 has flash memory of 32KB out of which 0.5KB is being used by boot loader.
- It has SRAM of 2 Kb size.
- It has EEPROM of 1 Kb size.
- The input voltage recommended by the company is 7 – 12 V.
- USB Overcurrent protection for more than 500mA.

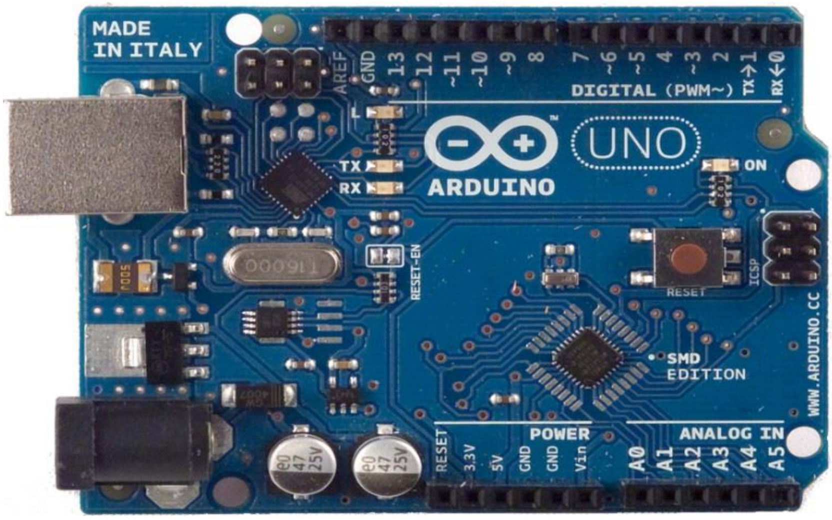


Figure 10: Arduino Uno SMD

4.2.2. Voltage Regulator : XC6203X332

It provides 3.3 volt output which is required by nrf24 module to be powered up.

XC6203X332 VOUT(T)=3.3V (Note1) Ta=25°C

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage	VOUT(E) (Note2)	VIN=4.3V IOUT=40mA	3.234	3.300	3.366	V
Maximum Output Current	IOUT max	VIN=4.3V $VOUT \geq VOUT(E) \times 0.96$	400			mA
Load Regulation	$\Delta VOUT$	VIN=4.3V $1mA \leq IOUT \leq 200mA$		40	100	mV
Dropout Voltage(Note3)	Vdif1	IOUT=100mA		150	220	mV
	Vdif2	IOUT=200mA		300	420	
Supply Current	ISS	VIN=4.3V		8.0	16.0	μA
Line Regulation	$\frac{\Delta VOUT}{\Delta VIN \cdot VOUT}$	IOUT=40mA $4.3V \leq VIN \leq 8.0V$		0.2	0.3	%/V
Input Voltage	VIN				8	V
Output Voltage Temperature Characteristics	$\frac{\Delta VOUT}{\Delta Topr \cdot VOUT}$	IOUT=40mA $-40^{\circ}C \leq Topr \leq 85^{\circ}C$		±100		ppm/°C

Table 3: XC6203X332 Electrical Characteristics

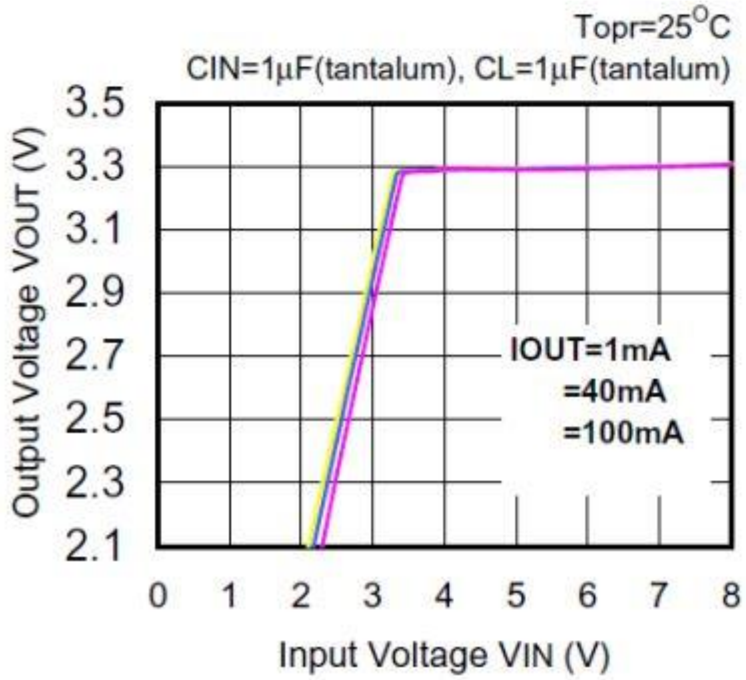


Figure 11: XC6203E332 Output Voltage vs. Input Voltage

4.2.3. The Nrf24L01+ Module

i.Introduction

It is a single chip 2.4GHz transmitter receiver chip with an integrated baseband protocol engine which is also called Enhanced ShockBurst. It is very much suitable for very low power communication (wireless) applications. The nrf24 is designed to work in ISM (industrial, scientific, medical) frequency band of 2.4 to 2.4835GHz.

By using a single microcontroller and few other passive components can design a RF radio with nrf24. By using serial peripheral interface (SPI) nrf24 can be configure and operate. Register map contains all configuration registers, which can be accessed by the SPI. This register map is accessible in all operating modes on nrf24 chip.

The Enhanced ShockBurst depends upon data packet communication. It is also called Embedded Baseband Protocol Engine. For advanced autonomous protocol operations various manual operating modes are up kept by it. An even and smooth flow of information between Nrf24 module and microcontroller is ensured by internal transmitter or receiver FIFOs. The system cost is also reduced by Enhanced ShockBurst protocol because all of the tasks which take place at high speed link layer are handled by it.

GFSK modulation/Demodulation is utilized by the RX and TX front end. User configurable variables such as output power, frequency channels, and data rate are present in Nrf24. Air data rates of 1Mbps, 2Mbps and 250Kbps are programmable in Nrf24. The two power saving modes combined with high air data rate make the nrf24 to work with ultra-low power wireless communication applications.

A good power supply rejection ratio (PSRR) is being ensured by internal voltage regulators. Hence it is having wide range of power supply [3].

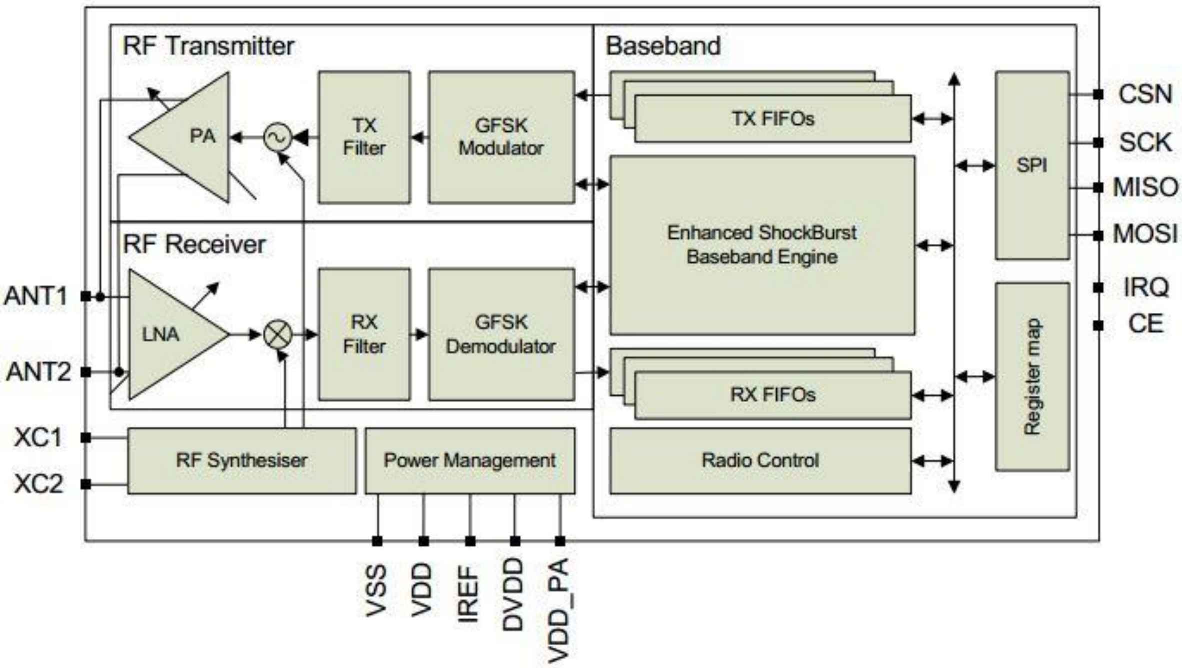


Figure 12: Nrf24L01+ block diagram

ii. Features

1. Radio

- ISM band operates at 2.4GHz world wide
- 126 no. of RF channels.
- Shared RX and TX interface
- GFSK modulation
- 2Mbps, 1Mbps, and 250Kbps air data rates.
- 1 MHz non overlapping channels spaced at 1Mbps.
- 2 MHz non overlapping channels spaced at 2Mbps.

2. Transmitter

- 0, -6, -12, and -18dBm output programmable power.
- 11.3mA current at 0dBm output power

3. Receiver

- Improved dynamic range due to fast AGC.

- Integrated channel filters.
- At 2Mbps 13.5mA current.
- - 82dBm of sensitivity at 2Mbps.
- - 94dBm of sensitivity at 250Kbps.

4. RF Synthesizer

- Fully integrated synthesizing element.
- VCO resonator or varactor diode, none external loop filter.
- Low cost 16MHz crystal +60ppm or -60ppm I s accepted.

5. Enhanced ShockBurst

- Dynamic payload length is 1-32 bytes.
- Automatic packet handling.
- Packet transaction handling is automated.
- For 1:6 star network, 6 data pipe MultiCeiver.

6. Power Management

- Fully integrated voltage regulator.
- Supply range 1.9 -3.6 volts.
- For advance power management fast start up times along with idle modes.
- 26μA current for standby mode I.
- 900nA current for power down mode.
- 1.5ms max startup delay from power down mode.
- 130 μs max startup delay from standby mode-I.

7. Host Interface

- Hardware SPI with four pins.
- 10 Mbps max data rate.
- 3 separate RX and TX FIFOs of 32bytes.
- 5V tolerant input pins.

8. QFN package with compact 20 pin 4*4 mm.

iii.Pin Information

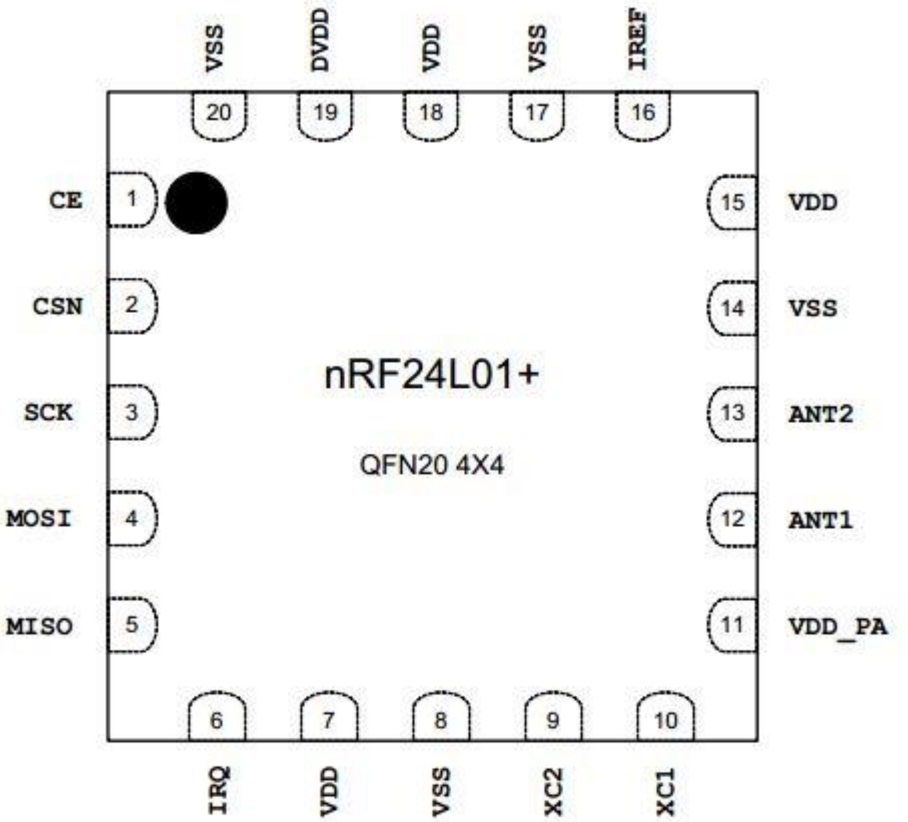


Figure 13: Pin assignment of nrf24L01

iv. Pin Functions

Pin	Name	Pin function	Description
1	CE	Digital Input	Chip Enable Activates RX or TX mode
2	CSN	Digital Input	SPI Chip Select
3	SCK	Digital Input	SPI Clock
4	MOSI	Digital Input	SPI Slave Data Input
5	MISO	Digital Output	SPI Slave Data Output, with tri-state option
6	IRQ	Digital Output	Maskable interrupt pin. Active low
7	VDD	Power	Power Supply (+1.9V - +3.6V DC)
8	VSS	Power	Ground (0V)
9	XC2	Analog Output	Crystal Pin 2
10	XC1	Analog Input	Crystal Pin 1
11	VDD_PA	Power Output	Power Supply Output (+1.8V) for the internal nRF24L01+ Power Amplifier. Must be connected to ANT1 and ANT2
12	ANT1	RF	Antenna interface 1
13	ANT2	RF	Antenna interface 2
14	VSS	Power	Ground (0V)
15	VDD	Power	Power Supply (+1.9V - +3.6V DC)
16	IREF	Analog Input	Reference current. Connect a 22kΩ resistor to ground.
17	VSS	Power	Ground (0V)
18	VDD	Power	Power Supply (+1.9V - +3.6V DC)
19	DVDD	Power Output	Internal digital supply output for de-coupling purposes.
20	VSS	Power	Ground (0V)

Table 4: Pin functions for nrf24

4.2.4. Temperature Sensor : LM35

LM35 series are precision integrated circuit temperature sensors. Its output voltage is linearly proportional to centigrade (°C) temperature scale. Hence to get scaling in convenient centigrade (°C), one does not need to subtract a large constant value from the output of the sensor. Thus all these sensors have an extra advantage over linear scale sensors which are calibrated in Kelvin (°K) scale. To achieve the room temperature accuracy of ±¼°C and ±¾°C over a temperature range of -55°C to 150°C trimming or any external calibration is not required by LM35. Calibration and trimming at wafer level ensures a low cost design. The low output impedance precise inherent calibration, and linear output of LM35 make interfacing to control circuitry or readout especially easy. Single power supplies or negative and positive supplies are used with the device. As only 60 µA current is drawn by LM35 from the power supply, it has self-heating less than 0.1°C with still air.

Features

- Directly calibrated in °C degree Celsius (centigrade).
- + 10 mV/°C linear °C scale factor.
- Ensures accuracy of 0.5°C at 25°C.
- Full temperature −55°C to +150°C Range.
- Suitability for remote applications.
- It has wafer level trimming because of it LM35 is having a low cost.
- Operating voltage 4 - 30 V.
- Drain current is less than 60µA.
- In still air very low self-heating, 0.08°C.
- Typically only ±¼°C nonlinearity.
- Very low output impedance 0.1 Ω for 1mA load.

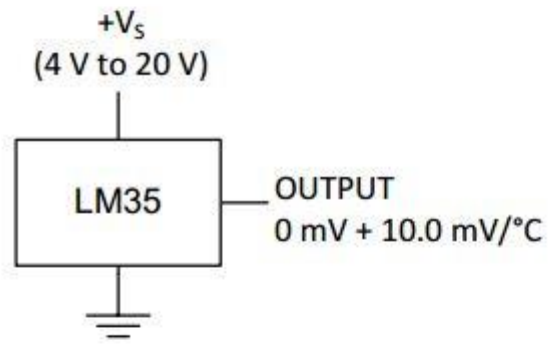


Figure 14: Basic Centigrade Temperature Sensor (+2°C to +150°C)

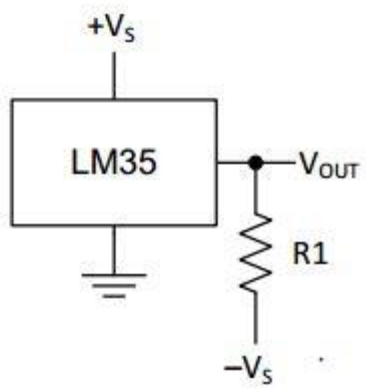


Figure 15: Full Range Centigrade Temperature Sensor

4.2.5. PIR Motion Sensor

PIR sensors are used to detect motion. They are used to detect the human in the sensor range. They are easy to use, don’t wear out, low power, low cost and low size. This is the main reason why they are often found in the applications we use at industry, businesses or homes. They are often called as “pyro electric” “IR motion sensors” or “passive infrared” sensors.

PIRs mainly consists of a pyro electric sensor and we can detect level of infrared radiations with it. Each body emits some infrared radiations. Hotter it is, more will be the radiation. Sensor inside the motion detector is actually split in two parts. The main reason for that is that we are interested in detecting the motion not IR levels.

The output of two halves are connected in a way such that these will get subtracted and we get the difference if there is any. If there is an output high or low then the motion is detected.

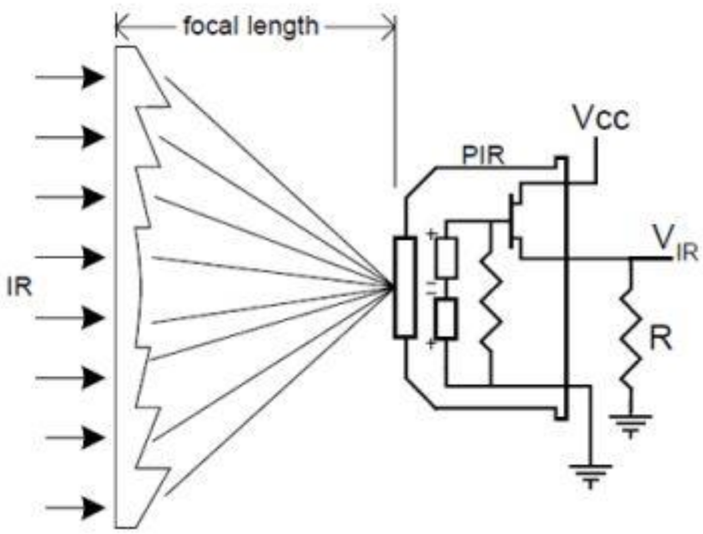


Figure 16: Connection diagram of PIR

Features

- Rectangular size.
- Digital high voltage pulse is 3V when motion is being detected.
- Having sensitivity range 6 meters (20 feet), for detection range is 110° x 70°.
- Ideal power supply 5 V. But will work in range of 3-9V

Working diagram

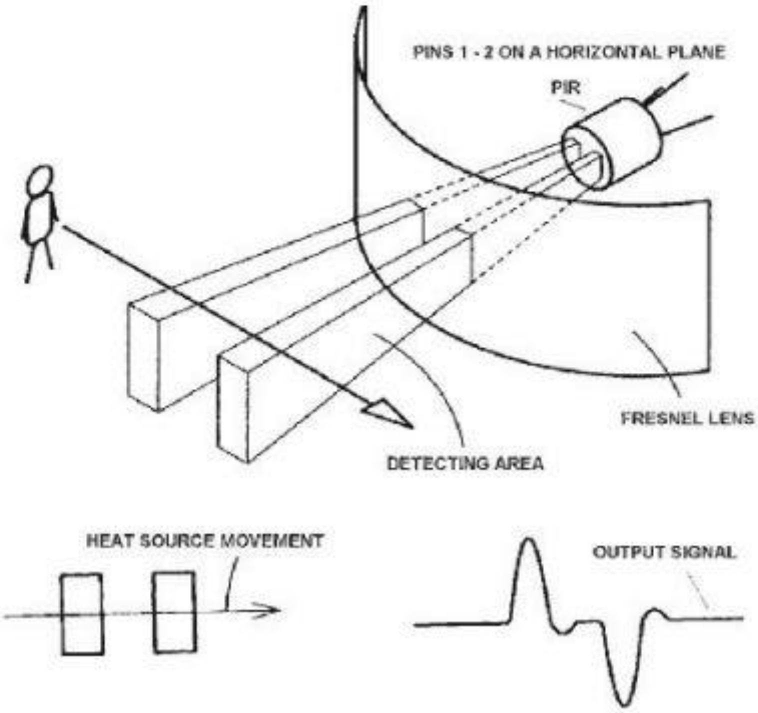


Figure 17: working of PIR

4.2.6. Light Dependent Resistor

Two photoconductive cells made of cadmium sulphide (CdS) with electrical characteristics same as human eye creates (LDR) light dependent resistor. If the intensity of light increases the cell resistance decreases.

Features

- Has a wider spectral response
- Inexpensive.
- Wider ambient range of temperature.

Electrical characteristics

Parameter	Conditions	Min.	Typ.	Max.	Units
Cell resistance	1000 lux 10 lux	- -	400 9	- -	Ω kΩ
Dark resistance	-	1.0	-	-	MΩ
Dark capacitance	-	-	3.5	-	pF
Rise time 1	1000 lux 10 lux	- -	2.8 18	- -	ms ms
Fall time 2	1000 lux 10 lux	- -	48 120	- -	ms ms

Table 5: LDR electrical characteristics

Chapter 5

Hardware construction and Software Implementation

5. Hardware construction and Software Implementation

5.1.Hardware construction

When the hardware design was completed the next task was to turn up the design in real world.

The construction of hardware was not much of a tough task because the raw material was available and user just had to mount all the components and solder them. ATtiny85 microcontroller controls all three sensor nodes those were constructed.

The initial plan was to construct a receiver (base station) with ATmega32 same as sensor nodes but finally this was found out that Arduino Uno can be used as receiver (base station) which initially was being used as programmer to upload the program into ATtiny85 flash. Also there was no requirement for LCD displays now because of graphical interface (GUI) of Arduino Uno.

The interface of nrf24 with Arduino Uno board will remain unsoldered as we are not able to permanently solder them with the portable ports of board. System will tends the flexibility because of this.

Figures 18, 19, and 20 show pictures of sensor nodes and Arduino as receiver.

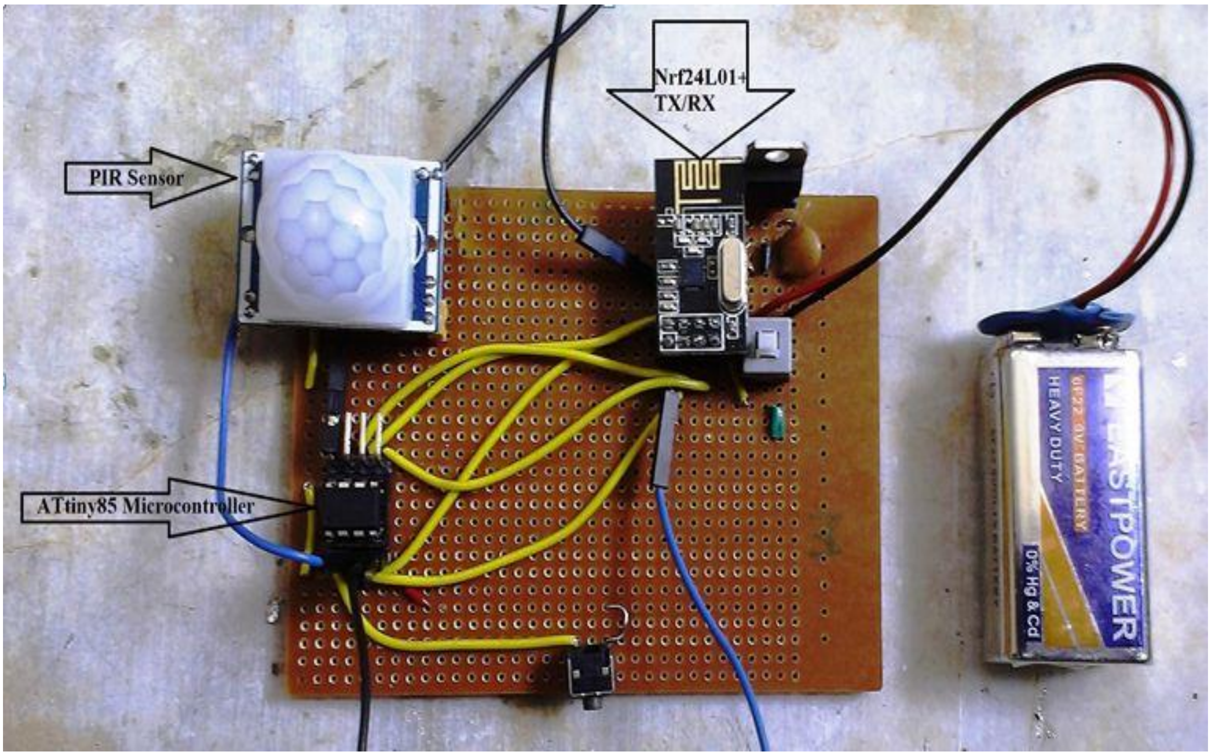


Figure 18: PIR Motion Sensor

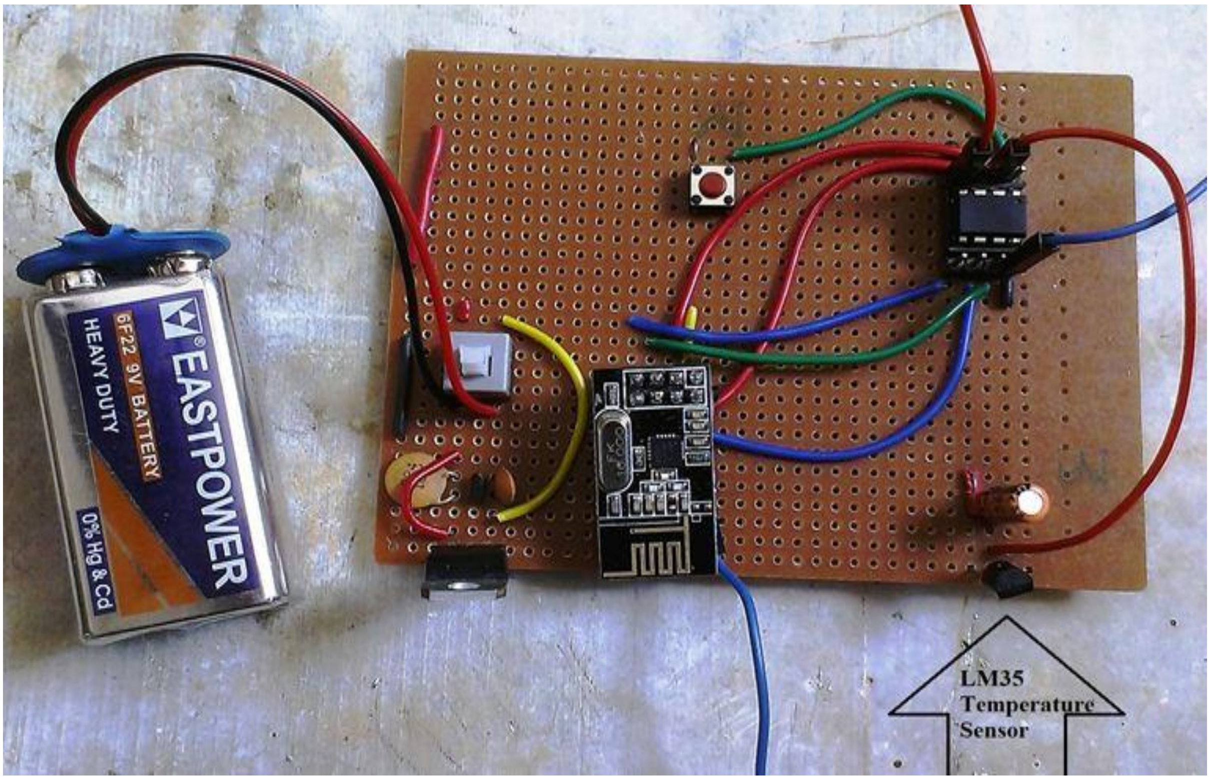


Figure 19: Temperature Sensor

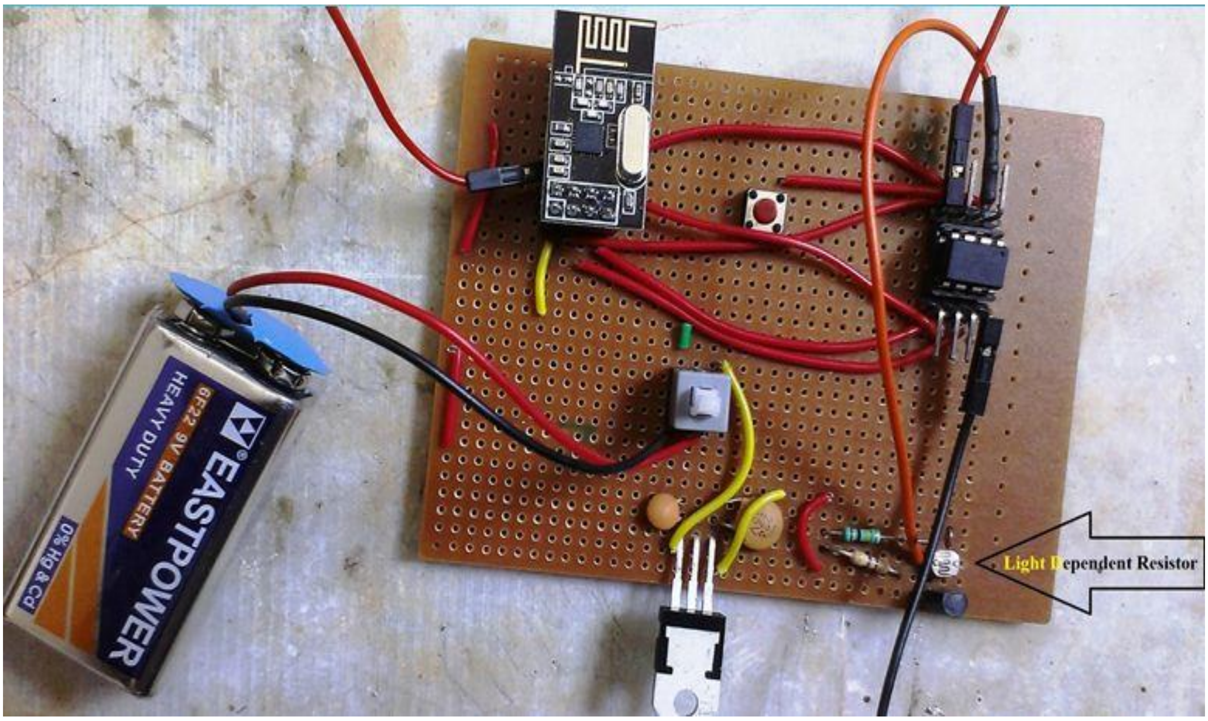


Figure 20: LDR

5.2. Software Implementation

With the help of Arduino Uno it was needed to upload sketches into both ATtiny85 and ATmega328 microcontroller flash memory. Programming of microcontroller was done using SPI interface with the help of ISP connections. The sketches were needed to carry out following tasks:

1. Convert integrated USI inside ATtiny85 to work as SPI.
2. Initialize software SPI to communicate with nrf24 module.
3. Obtain digitized sensor analog data from A/C convertor.
4. Transfer the information to Nrf24 module and then they are to be transmitted.
5. Transfer received information from Nrf24 to base station (ATmega328 microcontroller).
6. Display the information at PC - Arduino GUI.

All the programs have been written in Arduino 1.0.5-r2 IDE in C/C++ language. Programs are then uploaded to microcontroller flash memory using SPI interface and ISP connectors.

The program is divided into these parts:

1. Initialization and configuration of microcontroller integrated modules and nrf24L01+. This stage basically consists of these steps:
    - ATtiny85 microcontroller Pin configuration.
    - Microcontroller's A/D convertor initialization
    - SPI configuration
    - Nrf24's Transmitter and Receiver configuration

2. The Main Loop: the instructions specified in this part of program are repeated until a reset condition.

5.2.1. Pin Configuration

In this section of the program the write register instruction will define the nature of the I/O pin whether it is going to work as input or output. The value of each digital buffer latch is set or reset whenever it is necessary, if an output constant “1” or “0” is going to be needed.

Some of the pins can also have a different function that means they have a property of remap ability. Software part will assign to the pins these functions. This will depends on pin which is going to be needed, pin can work as a digital I/O pin , an analog input pin, a reference clock output, communication port line (SPI, ISP, …) or a PWM output. Programmable multiplexers are used by AVR family to provide these features. Figure 21 describes a functional block diagram of pin of AVR.

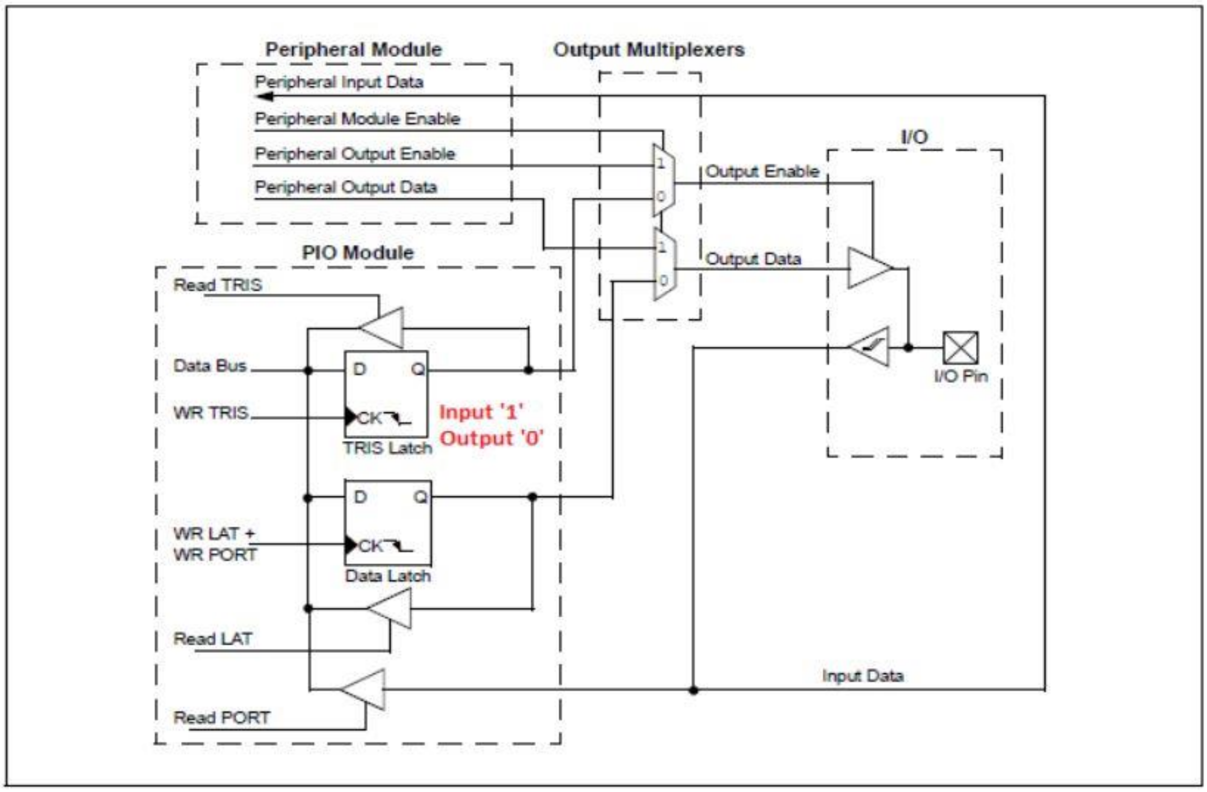


Figure 21: Block diagram of a shared port structure

5.2.2. ADC Convertor Initialization

- Conversion is done by Successive approximation register (SAR).
- Voltage reference for ADC can be selected by REF [2:0] bits in ADSC register.
- MUX [3:0] bits are used to select differential gain and analog input channel in ADMUX register.
- ADC enable bit ADEN in ADSCRA register is used to enable ADC.
- There is no power consumed if ADEN bit is clear.
- 10-bit data generated by ADC is present in ADC data registers ADCH and ADCL.
- Result is by default right adjusted and to present it as left adjusted set the bit ADLAR in register ADMUX.
- Conversion is started by setting ADSC bit in ADSCRA register.

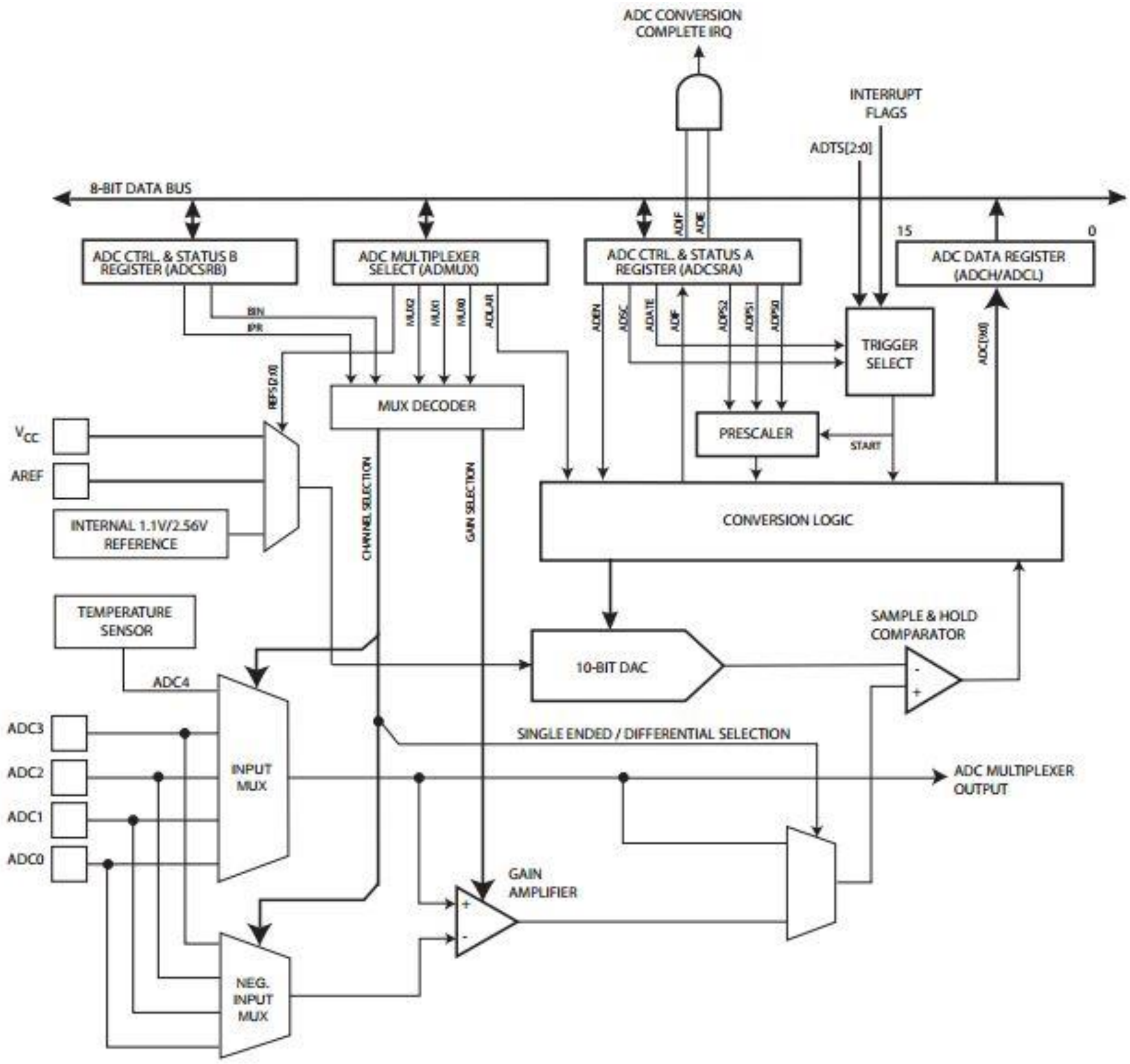


Figure 22: analog to digital convertor block diagram

5.2.3. SPI Configuration

It is data and control interface for nrf24. It gives access to nrf24's all features. This interface contains six digital signals that are 5V tolerant.

- IRQ (Interrupt request)
- CE (chip enable is used to put chip in TX or RX mode).
- CSN (chip select not-SPI signal).
- SCK (Serial Clock- SPI signal).

- MOSI (Master out Slave In - SPI signal).
- MISO (Master in Slave Out - SPI signal).

The SPI used in nrf24 is standard SPI with 10 Mbps of max data rate. Table 6 shows the standard SPI commands. To start a new command there should be a high to low transition on CSN pin.

Command name	Command word (binary)	# Data bytes	Operation
R_REGISTER	000A AAAA	1 to 5 LSByte first	Read command and status registers. AAAAA = 5 bit Register Map Address
W_REGISTER	001A AAAA	1 to 5 LSByte first	Write command and status registers. AAAAA = 5 bit Register Map Address Executable in power down or standby modes only.
R_RX_PAYLOAD	0110 0001	1 to 32 LSByte first	Read RX-payload: 1 – 32 bytes. A read operation always starts at byte 0. Payload is deleted from FIFO after it is read. Used in RX mode.
W_TX_PAYLOAD	1010 0000	1 to 32 LSByte first	Write TX-payload: 1 – 32 bytes. A write operation always starts at byte 0 used in TX payload.
FLUSH_TX	1110 0001	0	Flush TX FIFO, used in TX mode
FLUSH_RX	1110 0010	0	Flush RX FIFO, used in RX mode Should not be executed during transmission of acknowledge, that is, acknowledge package will not be completed.
REUSE_TX_PL	1110 0011	0	Used for a PTX device Reuse last transmitted payload. TX payload reuse is active until W_TX_PAYLOAD or FLUSH TX is executed. TX payload reuse must not be activated or deactivated during package transmission.
R_RX_PL_WID[a]	0110 0000	1	Read RX payload width for the top R_RX_PAYLOAD in the RX FIFO.
W_ACK_PAYLOAD[a]	1010 1PPP	1 to 32 LSByte first	Used in RX mode. Write Payload to be transmitted together with ACK packet on PIPE PPP. (PPP valid in the range from 000 to 101). Maximum three ACK packet payloads can be pending. Payloads with same PPP are handled using first in - first out principle. Write payload: 1– 32 bytes. A write operation always starts at byte 0.
W_TX_PAYLOAD_NOACK[a]	1011 0000	1 to 32 LSByte first	Used in TX mode. Disables AUTOACK on this specific packet.
NOP	1111 1111	0	No Operation. Might be used to read the STATUS register

Table 6: Commands for SPI+NRF24L01+

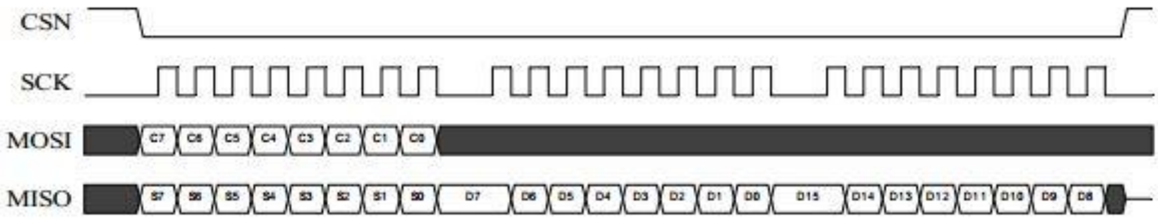


Figure 23: SPI read timings

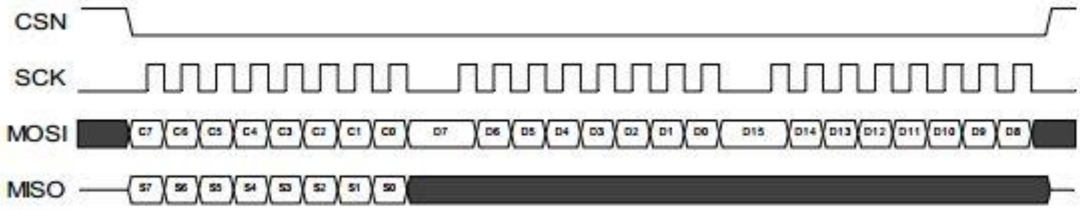


Figure 24: SPI write timings

5.2.4. NRF24L01+ Transmitter and Receiver Configuration

To enter RX mode Nrf24L01+ should have PRIM_RX bit high. CE pin and PWR_UP bit should also be high. In this mode the data that is received is demodulated and it is presented to baseband protocol engine constantly. This protocol engine always looks for a valid packet. If a packet have a matching address and a valid CRC than the payload present in packet is loaded into empty slot of RX FIFO. The packet is rejected if there is no empty slot in RX FIFO.

The nrf24 will stay in RX mode until it is instructed to go back in standby mode or power down mode by MCU. Received power detector signal is available in RX mode.

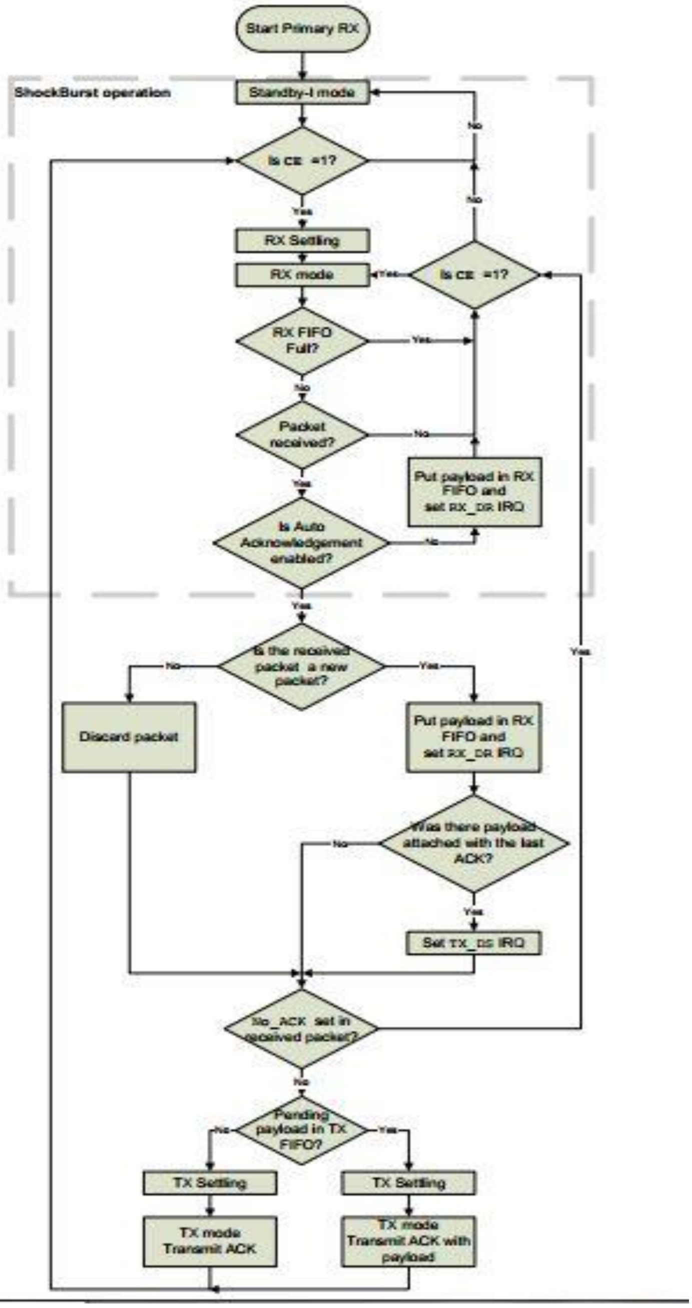


Figure 25: PRX Operations

Using CE pin high and PRIM_RX low we can activate TX mode. It will go into transmission mode if there is a data to transmit in TX FIFO. If an ACK signal is received then only it will transmit next data in FIFO. Otherwise it will retransmit the data until a limit is reached for retransmission. It is advised not to keep nrf24 in transmission mode for more than 4ms.

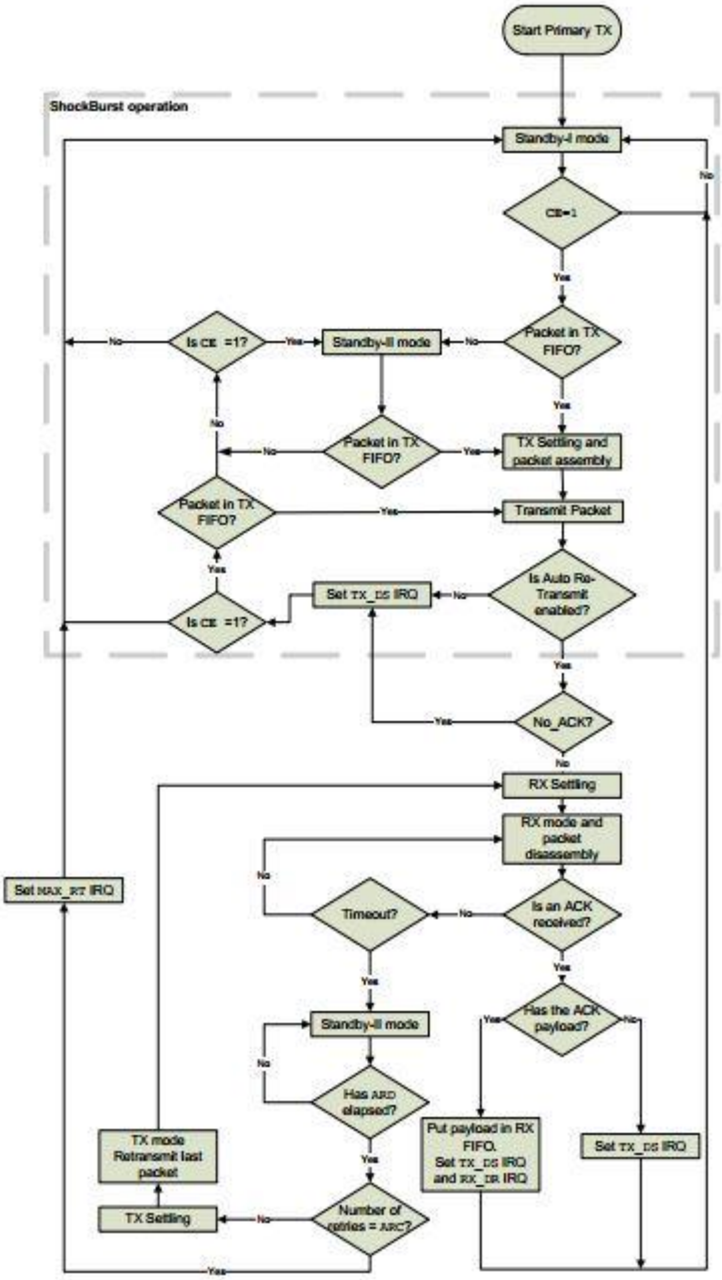


Figure 26: PTX Operation

Chapter 6

RESULT

6. Results

Three Nrf24l01+ prototype nodes have been built. Each of the node is capable of:

- Communicating over the air using its Nrf24L01+ Module.
- Sending sensory data from microcontroller to nrf24.
- Receiving data and then send it to PC for display.
- Transferring commands from PC to Nrf24 Module.
- Nodes are working as an interface between nrf24 network and user. A user can easily configure and manage the network.
- The In-sytem programming facility is also implemented. With the help of this facility user can program and reprogram the microcontroller inside the end system itself.

Some of the functionality could not be achieved:

- Continuous monitoring of the Environmental quantity, if more control over sensor nodes is desired.
- Enhanced ShockBurst protocol Engine could not be initialized properly.
- Some delay in the output of PIR motion sensor.

Chapter 7

Conclusion and Future Work

7. Conclusion and Future Work

The system has been tested in real time Environment and issues related to improper functioning has been identified. The system can be very useful in many industrial applications and household security systems. The functions performed by the system can easily identify the unwanted behaviour of Environmental quantity. Functionality issues can be overcome by the selection of more suitable components at sensor nodes. The performance of the nodes is efficient and power consumed by the nodes is minimum as possible. Size of the nodes is reduced considerably.

The outcome of the project can be used to draw graphs for permanent records using MATLAB interfacing with Arduino. The number of nodes can be increased to have more quantitative measurements. Nrf24l01 can be used more efficiently with ATtiny85 if two of the seven pins are multiplexed together. This will leave an I/O pin of microcontroller free to connect the sensor.

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